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Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia

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ABSTRACT

This paper investigates the dynamic causal relationships between energy consumption, energy price and economic activity in Saudi Arabia based on a demand side approach. We use a Johansen multivariate cointegration approach and incorporate CO_2 emissions as a control variable. The results indicate that there exists at least a long-run relationship between energy consumption, energy price, carbon dioxide emissions, and economic growth. Furthermore, a long-run unidirectional causality stands from energy consumption to economic growth and CO_2 emissions, bidirectional causality between carbon dioxide emissions and economic growth, and a long-run unidirectional causality runs from energy price to economic growth and CO_2 emissions. In the short-run, there is unidirectional causality running from CO_2 emissions to energy consumption and economic output and from energy price to CO_2 emissions. Even though, the energy-led growth hypothesis is valid, the share of energy consumption in explaining economic growth is minimal. Energy price is the most important factor in explaining economic growth. Hence, policies aimed at reducing energy consumption and controlling for CO_2 emissions may not reduce significantly Saudi's economic growth. Investing in the use of renewable energy sources like solar and wind power is an urgent necessity to control for fossil fuel consumption and CO_2 emissions.

Contents

1. Introduction

Energy use is essential to all economic activities and to human well-being. Lack of access to reliable and affordable modern energy represents a constraint to economic and social development in many parts of the world. By contrast, Saudi Arabia is from the countries

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Table 1
Energy statistics for Saudi Arabia in 2012.
Source: [2].

	Quantity	Share of total in the world (%)	Rank in the world	Change 2012 over 2011 (%)
Oil proved reserves (million tons) (a)	36,500	15.9	2	0.16
Oil production (million tons)	547.0	13.3	1	3.7
Oil consumption (million tons)	129.7	3.1	6	3.9
Natural gas proved reserves (trillion cubic meters)	8.2	4.4	6	1.0
Natural Gas: production (million tons oil equivalent)	92.5	3.0	7	11.1
Natural gas consumption (million tons oil equivalent)	92.5	3.1	6	11.1
Carbon dioxide emissions (million tons CO_2)	615.3	1.8	9	6.4

(a): 1 metric ton = 2204.62 lb.

which are well endowed of fossil fuel resources. Its endowment in fossil fuel resources has caused over-use of energy and high levels of CO_2 emissions. Studying the relationship between energy consumption[1] and economic growth in Saudi Arabia is imperative. Saudi Arabia owns important oil and gas resources, making it the richest country in the Arab world (Table 1). Saudi Arabia was the world's largest producer of oil in 2012, and the world's second largest holder of crude oil reserves. Saudi Arabia's economy is heavily dependent on fossil fuels. Fossil fuel exports accounted for about 90% of total Saudi export revenues in 2011 according to the Organization of the Petroleum Exporting Countries (OPEC). Its GDP ranks twentieth in the world [1]. In Saudi Arabia, energy consumption is extensively subsidized leading to overuse and misallocation of oil and natural gas resources. The subsidization of energy has given little incentive for its fast-growing population to save energy consumption in the different economic activities.[2] The GDP per unit of energy use in Saudi Arabia was about PPP US$ 3.688 per kg of oil equivalent in 2010. Energy use per capita was close to 6168 kg of oil equivalent in 2010, which was the highest in the world and also well above the global average (1851 kg of oil equivalent in 2010). Moreover, Saudi Arabia is the world's largest exporter of oil. Energy exports represent an important component of Saudi Arabia's GDP. Total natural resource rents represented 53.73% of GDP in 2010, in which 50.46% from oil and 3.24% from natural gas [1]. These rents can be used to promote renewable energy sources. Energy use in Saudi Arabia relies solely on fossil fuels (oil and natural gas), generating huge CO_2 emissions that contribute to global climate changes. According to [1], CO_2 emissions per capita were close to 16 metric tons in 2009 (4.7 metric tons in 2009 in the world; 17.27 metric tons in 2009 in USA; 7.22 metric tons in 2009 in European Union). Saudi Arabia is one of the largest global polluters; reducing CO_2 emissions is thus necessary. The check of conservation hypothesis is interesting to see if policies aimed at reducing energy consumption can affect Saudi economic growth or not.

We test the following hypotheses: (1) the "conservation hypothesis," which implies unidirectional causality from economic growth to energy use; (2) the "growth hypothesis" that assumes unidirectional causality from energy use to economic growth (implying energy consumption is a complement to capital and labor in output production); (3) the "feedback hypothesis," which assumes bidirectional causality between the two variables; and (4) the "neutrality hypothesis," implying the absence of causality between the two variables. The last hypothesis implies that neither conservative nor expansive policies regarding energy consumption have an impact on economic growth. Each hypothesis has policy implications concerning the management of energy use by national policy makers.

Findings from studies investigating the relationship between energy consumption (or electricity consumption) and economic activity share no consensus concerning the direction of causality between the two variables. They are sensitive to the analysis method, the sample period, the nature of variables included in the study, and to the country under investigation [2]. Energy economists have used four different approaches to investigate the relationship nexus between energy use and economic output: (a) a traditional VAR model that considers stationary series and Granger's causality tests (e.g. [3]); (b) the two step cointegration procedure of Granger (e.g. [4]); (c) the multivariate cointegration approach of [5] (e.g. [6]); and (d) panel cointegration and error correction methods (e.g. [7]).[3] Few studies have verified and investigated the relationship between energy consumption and economic growth for the OPEC members or the six member states of the Gulf Cooperation Council (GCC), and also for Saudi Arabia [8–18]. Findings from these studies are inconclusive and often contradictory.

The purpose of this study is to examine the causality amongst energy consumption, energy prices, CO_2 emissions, and economic growth in Saudi Arabia over the period of 1971–2010 using the multivariate cointegration approach of [5]. In contrast to previous studies that have investigated the nexus energy consumption economic growth for a panel of oil-exporting countries, our study concerns only Saudi Arabia. As shown by [11,12,18], studying the relationship between energy consumption and output without including additional variables lead to variable bias. To overcome this, we include energy price in the model and we add CO_2 emissions per capita as a control variable. Our study complements the work of [17] that examines the relationships between economic growth, CO_2 emissions and energy consumption at the aggregate and disaggregates levels for Saudi Arabia over the period of 1980–2011.

We organize the rest of the paper as follows. Section 2 presents material and methods. We begin the section by a brief literature review on the causal relationship between energy consumption and economic growth for oil exporting countries; then we present an overview of energy situation in Saudi Arabia; and finally we present data and methodology. Section 3 reports the empirical results. In Section 4, we discuss our results. The last section concludes by some policy implications and recommendations.

2. Material and methods

2.1. A brief literature review

The relationship between energy consumption and economic growth was first studied by Kraft and Kraft [3] for the USA. For a

[1] We use here the terms "fossil fuel consumption", "energy consumption" and "energy use" without distinction.

[2] Energy subsidies are measures which keep energy prices for consumers below market levels or for producers above markets levels, or reduce costs for consumers and producers.

[3] The references listed here for the four approaches are not exhaustive.

detailed survey of literature, see [2,19,20]. The literature review of energy consumption-economic growth causality nexus shows that most empirical studies investigate either the role of energy in either stimulating or suppressing economic growth. This has led to two opposite views. The first point suggests that energy is neutral to growth, known as the 'neutrality hypothesis' which proposes that the cost of energy is a small proportion of GDP resulting in insignificant impact. The second suggests that energy consumption is a limiting factor to economic growth. The impact of energy consumption on growth will depend on economic structure and the exact stage of a country's growth. As its economy grows, a nation's production structure is likely to shift toward services that are not energy intensive [21–23]. Even though the importance of energy to economic growth has become evident, there are reservations about some findings. There is no consensus regarding the existence or direction of causality between energy consumption and economic growth. Policy implications of these relationships can be significant in providing policy recommendations that can be applied across countries. To avoid conflicting and unreliable results, previous studies have used approaches like the autoregressive distributed lag (ARDL) bounds test, two-regime threshold co-integration model, panel data models, and multivariate cointegration models by considering some variables of control. Results for OPEC countries, including Saudi Arabia, remain ambiguous. Earlier studies on the causal relationship between energy consumption and economic output are somewhat contradictory.

Al-Iriani [8] studied the causal relationships between energy consumption and economic activity for the Gulf Cooperation Council countries[4] over the period 1970–2002 using a panel cointegration technique. He found that economic activity unidirectional Granger causes energy consumption, and hence a policy aimed at reducing energy consumption in these countries does not adversely affect economic growth. Mehrara [9] examined the causal relationship between per capita energy consumption and per capita GDP for a panel of 11 selected oil exporting countries, including Saudi Arabia by using panel unit-root tests and panel cointegration analysis over the period 1971–2002. His results are conform to those of Al-Iriani [8], showing a unidirectional strong causality running from economic growth to energy consumption for oil exporting countries. These findings have practical policy implications for decision makers in macroeconomic planning. In most major oil exporting countries, government policies keep domestic prices below free market level, resulting in high levels of domestic energy consumption. Energy conservation through reforming price policies thus has no damaging repercussions on economic growth for these countries. The drawback of this study does not include control variables, such as fuel prices or CO_2 emissions, when considering the demand side approach and labor, or capital stock when considering the production function side approach.

Squalli [10] studied the causal relationship between electricity consumption and economic growth for 11 OPEC members using different tests over the period of 1980–2003. Results indicated a long-run relationship between electricity consumption and economic growth for all countries. For Saudi Arabia, the author found a bi-directional causality between electricity consumption and economic growth.

Narayan and Smyth [11] studied the relationship between electricity consumption and economic activity for Iran, Israel, Kuwait, Oman, Saudi Arabia, and Syria over the period 1974–2002. The authors included exports as a control variable and found a long-run bidirectional causal relationship between the variables and the absence of causality in the short-run. Using the multivariate panel cointegration technique and incorporating energy prices and trade as control variables, Sadorsky [12] seemed to agree with Narayan and Smyth [11], with the exception of bidirectional causality in the short-run for 8 Middle Eastern countries, including Saudi Arabia over the period of 1980–2007.

Alkhathlan et al. [13] investigated the relationships between energy consumption, CO_2 emissions, and economic growth for Saudi Arabia from 1980 to 2008 using both ARDL and Johansen cointegration approaches. They found that energy consumption and CO_2 emissions do not Granger cause economic output. The authors used a production function approach, in which economic output is explained by energy use, employment and CO_2 emissions. The authors failed to integrate capital stock as an explicative variable of economic output.

Khalid [14] studied the relationship between energy consumption and economic growth for Saudi Arabia over the period 1970–2008 using a Johansen cointegration approach. He found a unidirectional Granger causality running from economic growth to energy consumption in the long run and absence of causality in the short-run. However, this study is based on a two-variable specification of energy consumption–economic activity relationship, which is subject to omitted variables bias.

Hossein et al. [15] studied the causal relationships between energy consumption and economic output for OPEC countries using the multivariate cointegration approach. They found that for Saudi Arabia, a short-run unidirectional causality from economic growth to energy consumption exists, but no causal relationships between energy consumption, economic growth, and prices in the log-run. The authors conclude that the theory of resource curse is verified for countries studied.

Damette and Seghir [16] studied the energy consumption-economic growth nexus for 12 oil-exporting countries over the period 1990–2010 using panel cointegration techniques and accounting for cross-section dependence and structural breaks. They reported a short-run unidirectional causality from energy consumption to economic activity, and a reverse for the long-run. By examining the relationships between economic growth, carbon emissions and energy consumption at the aggregate and disaggregate levels for Saudi Arabia over the 1980–2011 period, Alkhathlan and Javid [17] found that economic growth and energy consumption cause carbon dioxide emissions in Saudi Arabia in both the short and long-run. They also found that energy consumption causes economic growth in the long-run, but there is no causal relationship in the short-run.

Along the same lines, Mohammadi and Parvaresh [18] investigated the dynamic causal relationships between energy consumption and output for 14 oil-exporting countries during the period of 1980 to 2007. They included only the possibility of cross sectional correlations. The authors used three alternative panel estimation techniques - the dynamic fixed effect, the pooled mean group, and the mean group estimators - and found stable relationship between the two variables and a bi-directional causality in both the long and short term.

2.2. Overview of energy sector in Saudi Arabia

Saudi Arabia has an abundant non-renewable and renewable energy sources. According to British Petroleum Statistical Review of World Energy [24], Saudi Arabia was the world's second largest holder of proved oil reserves and the world's sixth largest holder of proved natural gas reserves in 2012. At the end of 2012, the proved oil reserves were 36.5 thousand million tons, representing 15.9% of the world's total reserves [24].[5] Saudi Arabia is the largest

[4] The Gulf Cooperation Council is composed of the six countries of Bahrain, Kuwait, Qatar, Oman, Saudi Arabia and United Arab Emirates.

[5] Venezuela has the world's largest proved oil reserves with 297.6 thousand million barrels [24].

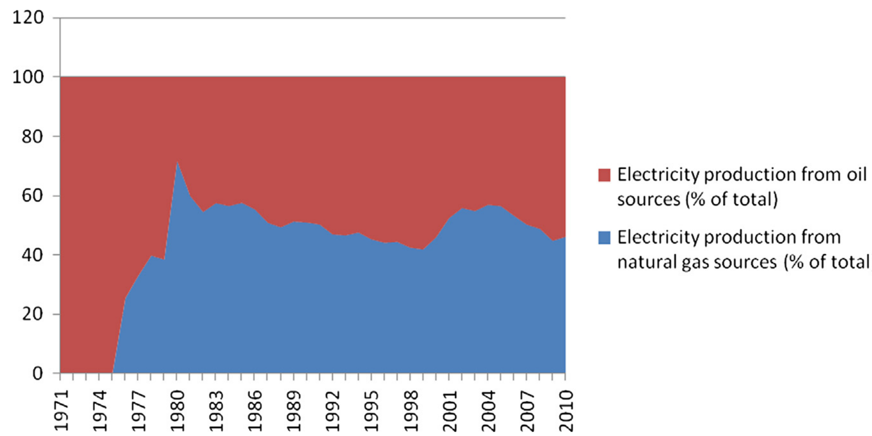

Fig. 1. Percentage of electricity production by fuel type in Saudi Arabia, 1971–2010.
Source: [1].

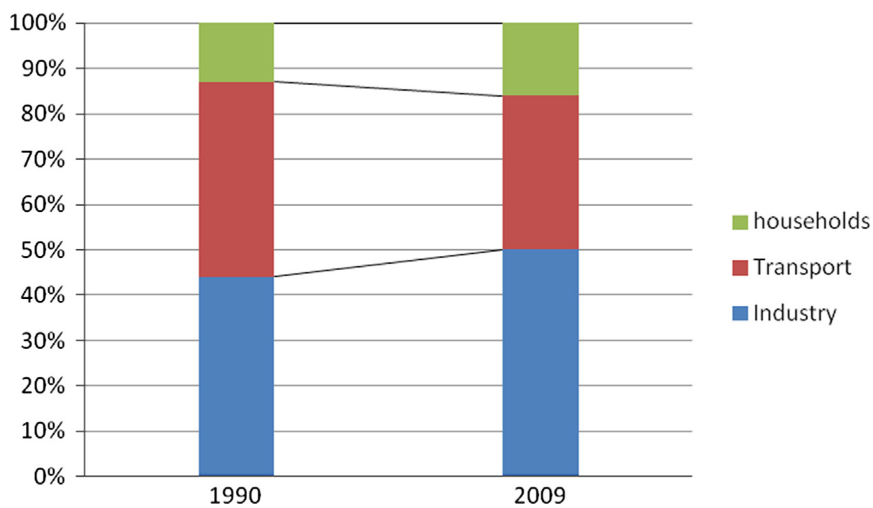

Fig. 2. Distribution of energy consumption by sector (%).
Source: [23].

producer of oil in the world. Its oil production represented 547.0 million tons in 2012 (representing 13.3% of the world's oil production) [24]. Its production accounted for about 92.5 million tons of oil equivalent in 2012. Furthermore, Saudi Arabia is the 20th largest producer and consumer of electricity in the world.

In the case of renewable energy, Saudi Arabia has also abundant wind and solar energy sources [22], but uses a negligible proportion to produce its electricity. Approximately all electricity is produced from fossil fuels: in 2010, approximately 53.85% of Saudi Arabia's electricity came from oil and the rest from natural gas [1]. Fig. 1 shows the distribution of electricity production from the two sources from 1971 to 2010.

Saudi Arabia is the world's sixth largest consumer of oil and natural gas. It is among the world's 10 countries whose energy consumption is higher than the global average rate. Saudi's oil consumption was about 129.7 million toe in 2012 (representing 3.1% of total world consumption) whereas its natural gas consumption was 92.5 million toe in 2012 (representing 3.1% of total world consumption).[6] About 50% of total energy consumption was used by the industry sector (including petrochemical uses) in 2009. The petrochemical sector accounted for 36% in 2009, followed by the transport sector (34%). Fig. 2 shows the distribution of energy consumption by sector in Saudi Arabia.

The large production and consumption of fossil fuels are not without CO_2 emissions consequences in Saudi Arabia, which was the world's ninth largest emitter of carbon dioxide emissions in 2012 (2.8% of total world emissions). Despite efforts made by Saudi Arabia to diversify its economy, the fossil fuel industry accounts for about 45% of GDP, 75% of budget revenues, and 90% of exports earnings [25]. Table 2 shows the growth rates of real GDP per capita, energy consumption per capita and CO_2 emissions per capita for decades within 1971–2010. Saudi Arabia experienced a rapid economic growth from 1971 to 1980: real GDP per capita increased by about 79% during this period whereas it had increased by only 28.51% over the last period of 2001–2010. Saudi Arabia's energy consumption per capita was 3.3 times higher than the world average at 6.168 toe in 2010. Energy consumption per capita increased by 405.3% between 1971 and 2010, observed mainly for the 1971–1980 decade, followed by decades of 1991–2000 and 2001–2010. Rates of CO_2 emissions per capita were also faster within 1971–1980 followed by 2001–2010. Although Saudi Arabia ratified the Kyoto Protocol in 2005, CO_2 emissions per capita increased by 13.44% between 2001 and 2010. The evolution of energy consumption per capita is faster than the other two variables during all sub-periods. The gap between energy consumption per capita growth and real GDP per capita growth is highest.

The GDP per unit of energy use (expressed in constant 2005 PPP $ per kg of oil equivalent) passed from 10.68 in 1980 to 3.33 in

[6] toe: tons oil equivalent.

Table 2
Saudi's growth rates of real GDP per capita, energy consumption per capita and CO_2 emissions per capita (%).
Source: [1].

Variables	1971–1980	1981–1990	1991–2000	2001–2010	1971–2010
Growth rate of real GDP per capita	79.01	−42.06	−0.41	28.51	33.59
Growth rate of Energy consumption per capita	159.97	−8.62	21.07	19.60	405.3
Growth rate of CO_2 emissions per capita	74.22	−19.65	−7.78	13.44	64.32

Table 3
Saudi's CO_2 emissions in 1980, 1990, 2000, and 2010 (% of total fuel combustion).
Source: [1].

CO_2 emissions	1980	1990	2000	2010
Electricity and heat production	38.12	53.30	58.18	56.34
Manufacturing industries and construction	39.83	14.39	16.65	19.35
Residential buildings and commercial and public services	1.50	1.58	1.31	0.89
Other sectors	0.99	0.00	0.00	0.00
Transport	19.56	30.73	23.86	23.42

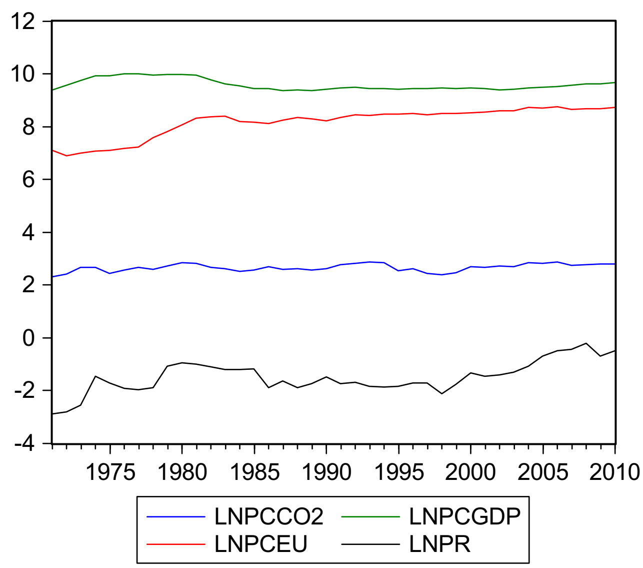

Fig. 3. The evolution of natural logarithms of per capita energy consumption, per capita GDP, energy price, and per capita CO_2 emissions.
Source: [1].

2010. Energy consumption per $1000 GDP (expressed in constant 2005 $ PPP) passed from 93.59 kg of oil equivalent in 1980 to 300.37 kg of oil equivalent in 2010 [1]. These figures show the intensity of energy economic activities in Saudi Arabia explained by overuse of energy and local low prices for fossil fuel consumption. Oil consumption in Saudi Arabia has risen rapidly since 1980 to attain about three million barrels per day. The EIA estimates that in peak summer months, when electricity demand for air conditioning is highest, Saudi Arabia burns more than one million barrels of oil per day to generate power. Saudi Arabia is subsidizing fossil fuels (oil and natural gas) and electricity by adopting measures in a way that these products reach consumers at low prices. Saudi government is paying the difference in price to preserve a standard price that is lower than that of the market or to decrease its costs. For example, the actual price of 1 l of diesel is approximately US$ 0.12. Saudi Arabia pays about 70% of the actual bill of energy prices consumed locally. According to the United Nations estimations, energy subsidies represent about 10% of the Saudi's GDP, in which 68% of subsidies are allocated to fossil fuels and 32% to electricity. These ratios are likely to increase in the future if urgent actions are not taken such as cutting energy subsidies, energy efficiency measures and investment in renewable energies (solar and wind resources), given that energy consumption is growing due to population growth, and urban and commercial development.

The extensive use of fossil fuels (oil and natural gas) in the different sectors of activities in Saudi Arabia has a negative effect on environment. Table 3 shows Saudi's CO_2 emissions from different sectors. CO_2 emissions from electricity and heat production are the largest in Saudi Arabia, representing 56.34% of total CO_2 emissions in 2010.

2.3. Data and methodology

We use the Johansen multivariate cointegration technique (1991) to examine the causal relationship between per capita energy consumption, energy prices, per capita carbon dioxide emissions and real per capita gross domestic product for Saudi Arabia. As Saudi Arabia is one of the largest producers of oil, it has largely subsidized energy prices in order to benefit its population from oil rents, promote industrial activities, generate employment, and enhance economic competitiveness [16]. Subsidization of energy has lead to very low national energy prices, which has increased energy consumption. Consequently, studying the relationship between energy consumption and economic growth on the demand side is the most suitable for analyzing this sector in Saudi Arabia. Incorporating energy prices with the economic output and energy consumption in the multivariate cointegration approach is an optimal strategy. Due to unavailability of data on national energy prices, we use a proxy of real energy price variable which is constructed by deflating the price of Dubai spot crude oil (measured in US dollars per barrel) to the Saudi's consumer price index (2005 = 100) as proposed by [12]. We also incorporate CO_2 emissions as a control variable. Annual data covering the period 1971–2010 are used for this study. Period length is dictated by data availability. Data on per capita energy consumption, per capita GDP, per capita carbon dioxide emissions and consumer price index are obtained from WDI [1] whereas data on the price of Dubai spot crude oil are obtained from British Petroleum Statistical Review of World Energy [24]. All data are converted into natural logarithms before conducting empirical research to induce a stationary series in the variance–covariance matrix. Fig. 3 shows the evolution of the four series expressed in natural logarithms over the investigated period, highlighting a common trend for the four variables. Descriptive statistics of the four variables are given in Table 4. The four series are named as follows: LNPCEU: natural

Table 4
Descriptive statistics.

Series	Description	Mean	Median	Std. Dev.	Max.	Min.
PCEU	Per capita energy consumption (in kg oil equivalent)	4011.46	4320.23	1637.53	6379.73	990.42
PCGDP	Per capita GDP (in constant 2000 US $)	14,893.53	12,985.21	3465.07	22,109.70	11,605.39
PR	Ratio of the price of Dubai spot crude oil (measured in US dollars per barrel) to the Saudi's consumer price index (2005=100)	0.268	0.211	0.169	0.806	0.056
$PCCO_2$	per capita CO_2 emissions (in metric tons)	14.34	14.36	2.02	17.75	9.92
Observations		40	40	40	40	40

logarithm of per capita energy consumption; LNPCGDP: natural logarithm of per capita GDP; LNPR: natural logarithm of energy price and $LNPCCO_2$: natural logarithm of per capita CO_2 emissions.

The Johansen cointegration approach is executed in four steps. In the first step, we apply the unit root tests in order to check for the stationary of the time series. We use both the usual unit root tests of augmented Dickey–Fuller (1979) (ADF) [26] and Phillips–Perron (1988) (PP) [27]. If the series are integrated of the same order and a stationary linear combination between their levels exists, they are considered cointegrated and long-run equilibrium relationships exist [28].

We find that the four series are integrated of the same order one and proceed to the second step with estimating a VAR model by considering the stationary series. Based on the AIC and/or SIC criteria, we determine the lag length to execute the Johansen's cointegration test in the third step. This test is based on the error correction representation of the VAR model as follows:

$$\Delta Y_t = a + \Phi C_t + \sum_{i=1}^{K-1} \Gamma_i \Delta Y_{t-i} + \Pi Y_{t-K} + \varepsilon_t \tag{1}$$

where either Y_t and Y_{t-i} include the natural logarithm of per capita energy consumption, real per capita GDP, energy price and per capita CO2 emissions; Δ is the first difference operator; a is the intercept, C_t represents the trend term, Π is a matrix; K is the order of the model and ε is a disturbance term independently and identically distributed with zero mean and constant variance.

The number of cointegrating vectors (r) that exist among the variables is determined by estimating the rank of the matrix Π based on the trace and maximum eigenvalue statistics. The Max–Eigen test statistic (λ_{max}) is determined under the null hypothesis, H_0: $r_0=r$, against the alternative hypothesis, H_1: $r_0>r$. The trace test statistic is determined under the null hypothesis, H_0: $r_0 \le r$, against the alternative hypothesis, H_1: $r_0>r$; where r_0 represents the number of cointegrating vectors [6]. The two tests are performed sequentially for $r=0$ to $r=K-1$ until we fail to reject the null hypothesis.

The Johansen's cointegration test does not indicate, however, the direction of causality between variables. If a set of variables are cointegrated, there must be short and long run causality which can be captured with the VECM framework [29]. Hence, in the fourth step, we estimate the vector error correction model (VECM), given by Eqs. (2)–(5), to carry out the short and long run Granger causality tests:

$$\Delta y_t = \alpha_1 + \sum_{i=1}^{k} \beta_{1i} \Delta y_{t-i} + \sum_{i=1}^{k} \lambda_{1i} \Delta x_{t-i} + \sum_{i=1}^{k} \mu_{1i} \Delta p_{t-i} + \sum_{i=1}^{k} \gamma_{1i} \Delta z_{t-i} + \eta_1 ECT_{t-1} + \varepsilon_{1t} \tag{2}$$

$$\Delta x_t = \alpha_2 + \sum_{i=1}^{k} \beta_{2i} \Delta x_{t-i} + \sum_{i=1}^{k} \lambda_{2i} \Delta y_{t-i} + \sum_{i=1}^{k} \mu_{2i} \Delta p_{t-i} + \sum_{i=1}^{k} \gamma_{2i} \Delta z_{t-i} + \eta_2 ECT_{t-1} + \varepsilon_{2t} \tag{3}$$

$$\Delta p_t = \alpha_3 + \sum_{i=1}^{k} \beta_{3i} \Delta p_{t-i} + \sum_{i=1}^{k} \lambda_{3i} \Delta y_{t-i} + \sum_{i=1}^{k} \mu_{3i} \Delta x_{t-i} + \sum_{i=1}^{k} \gamma_{3i} \Delta z_{t-i} + \eta_3 ECT_{t-1} + \varepsilon_{3t} \tag{4}$$

$$\Delta z_t = \alpha_4 + \sum_{i=1}^{k} \beta_{4i} \Delta z_{t-i} + \sum_{i=1}^{k} \lambda_{4i} \Delta y_{t-i} + \sum_{i=1}^{k} \mu_{4i} \Delta x_{t-i} + \sum_{i=1}^{k} \gamma_{4i} \Delta p_{t-i} + \eta_4 ECT_{t-1} + \varepsilon_{4t} \tag{5}$$

where y represents the natural logarithm of per capita energy consumption, x is the natural logarithm of real per capita GDP, p is the natural logarithm of energy price and z is the natural logarithm of per capita carbon dioxide emissions; Δ is the first difference; ECT_{t-1} are the error correction terms; andε_{1t}, ε_{2t}, ε_{3t} and ε_{4t} are the usual error terms.

The long run relationships are determined by the coefficients of the ECTs. If the variables, LNPCEU, LNPCGDP, LNPR and $LNPCCO_2$ are cointegrated, then it is expected that at least one or all the ECTs have negative coefficient and should be significantly non-zero. Short run Granger causality is determined by implementing a Wald test of the significance of the lags of each of the explanatory variables in each equation of the VECM: Eq. (2) – (H_0:$\lambda_{1i}=0$ for $i=1, \ldots, k$), (H_0:$\mu_{1i}=0$ for $i=1, \ldots, k$), (H_0:$\gamma_{1i}=0$ for $i=1, \ldots, k$); Eq. (3) – (H_0:$\lambda_{2i}=0$ for $i=1, \ldots, k$), (H_0:$\mu_{2i}=0$ for $i=1, \ldots, k$), (H_0:$\gamma_{2i}=0$ for $i=1, \ldots, k$); Eq. (4) – (H_0:$\lambda_{3i}=0$ for $i=1, \ldots, k$), (H_0:$\mu_{3i}=0$ for $i=1, \ldots, k$), (H_0:$\gamma_{3i}=0$ for $i=1, \ldots, k$); and Eq. (5) – (H_0:$\lambda_{4i}=0$ for $i=1, \ldots, k$), (H_0:$\mu_{4i}=0$ for $i=1, \ldots, k$), (H_0:$\gamma_{4i}=0$ for $i=1, \ldots, k$).

For example, the acceptance of the first null hypothesis in Eq. (2) implies that per capita GDP does not Granger-cause per capita energy consumption in the short run, and so on for all other variables.

The Granger-causality tests indicate only the existence of causality between the variables. To provide any indication how important is the causal impact of one selected variable on another variable and assess how each variable responds to innovations in other variables, we use the variance decomposition analysis by applying the Cholesky decomposition technique in VECM [30]. We use also the impulse response function to trace the effects of a shock to one endogenous variable on to the other variables. A shock to one variable not only directly affects this variable but is also transmitted to all of the other endogenous variables through the dynamic structure of the model [31,32].

3. Empirical results

3.1. Results of unit root tests

We test the existence of unit roots in natural logarithms of the four variables of per capita energy consumption, per capita GDP, per capita CO_2 emissions and energy price using three models (with trend and intercept, with only intercept, and without trend and intercept). The results of ADF and PP unit root tests are

Table 5
Results of ADF and PP unit root tests.

Variables	ADF test			PP test		
	t-Stat.		Critical values at 5% level	Adj. *t*-Stat.		Critical values at 5% level
	Levels	First differences		Levels	First differences	
$LNPCCO_2$	0.494	−6.359	−1.95	0.724	−6.510	−1.95
LNPCEU	2.232	−2.568	−1.95	1.660	−4.227	−1.95
LNPCGDP	−0.694	−3.329	−1.95	0.349	−3.469	−1.95
LNPR	−1.918	−6.285	−1.95	−1.911	−6.301	−1.95

Note: all the results are given for model 1 without intercept and trend. Each ADF *t*-statistic is reported for shortest lag length which has been chosen based on minimum AIC.

presented in Table 5. It is shown that all the four variables are non stationary at their levels at 5% critical value, whereas their first differences are stationary. Hence, LNPCEU, LNPR, LNPCGDP and $LNPCCO_2$ are integrated of order one. The four variables can thus be cointegrated.

3.2. Results of Johansen cointegration test

To determine if LNPCEU, LNPR, LNPCGDP and $LNPCCO_2$ are cointegrated, we apply the Johansen multivariate cointegration test. Before applying the test, we choose the optimum lag length which may be used for the Johansen cointegration test. Based on minimum AIC and SC through the estimation of the unconstrained VAR model for the first differences of the four variables under consideration, we obtain that the lag length is equal to one[7]. Here, we assume that the level data has no deterministic trends and the cointegrating equations have intercepts. We choose this specification because the unit root tests indicate that the four variables have no common deterministic trend. The cointegration rank, *r*, of variables is determined using the maximum eigenvalue and trace test statistics.

The results of Johansen cointegration test (Trace and Max–Eigen statistics) are given in Table 6. For the null hypothesis of no cointegration, the value of the trace statistic is equal to 88.15, which is superior to the 5% critical value of 53.12 and the 1% critical value of 60.16. Hence the null hypothesis of $r_0 \le 0$ is rejected at 5% and 1% levels of significance. The null hypothesis, $r_0 \le 1$, is also rejected at 5% and 1% levels of significance given that the trace statistic value of 47.427 is superior to the 5% critical value of 34.91 and the 1% critical value of 41.07. For the null hypothesis, $r_0 \le 2$, it is also rejected at 5% level of significance but it is accepted at 1% level of significance given that the trace statistic value of 22.228 is superior to the 5% critical value of 19.96 and it is less than the 1% critical value of 24.60. Hence, the trace test indicates the presence of two cointegrating equations at the 1% level. Finally, the null hypothesis, $r_0 \le 3$, is accepted at 5% level of significance given that the trace statistic value of 6.322 is less than the 5% critical value of 9.24. Hence, trace test indicates three cointegrating equations at the 5% level and two cointegrating equations at the 1% level.

The same analysis could be done for the results of Max–Eigen test. It indicates three cointegrating equations at the 5% significance level and one cointegrating equation at the 1% significance level. Hence, the results of trace and Max–Eigenvalue tests show the existence of at least one cointegrating relationship between energy consumption, energy price, carbon dioxide emissions and economic growth for Saudi Arabia. This means the existence of a long-run relationship between per capita energy consumption, per capita GDP, energy price and per capita CO_2 emissions for Saudi Arabia.

3.3. Results of Granger causality tests

Even though cointegration implies Granger causality, it fails to indicate the relationship direction. We investigate the short and long run causality between per capita energy consumption, per capita GDP, energy price and per capita CO_2 emissions for Saudi Arabia based on the vector error correction model. The VECM, given by Eqs. (2)–(5), is estimated for a one period lag chosen based on AIC and SC which are, respectively, equal to −4.261 and −3.172.[8] It is estimated by considering the long run relationship when the natural logarithm of per capita energy consumption is explained by the natural logarithms of per capita GDP, energy price and per capita carbon dioxide emissions. However, before applying the Granger causality tests, we check the robustness of VECM through the normality residual test of Jarque–Bera, the autocorrelation LM test, and the White VEC residual heteroskedasticity test. Results of VECM normality residual test are shown in Table 7. All the *p*-values (probabilities associated with test statistics) in the four equations and the joint one are above 5%. This implies that the normality residual test of Jarque–Bera indicates that we did not reject the null hypothesis of normality of residuals at a 5% level for the four individual equations and the joint. Results of VECM residual autocorrelation tests and heteroskedasticity tests are shown in Table 8. For a lag up to 12, the results of the autocorrelation LM and Portmanteau tests show that we accept the null hypothesis of no serial correlation at the 5% level. The results of the White VEC residual heteroskedasticity test show that we accept the null hypothesis of homosckedasticity at a 5% level with and without cross terms. Hence, the VEC model passes all the diagnostic tests without reservation.

Results of Granger causality tests are shown in Table 9. We consider the two types of tests for Granger causality. The first is the long-run causality determined by the significance of the error–correction terms. The second is the short-run causality known as "weak Granger causality" and determined by the joint significance of coefficients of lagged terms of each independent variable. As shown in Table 9, the coefficient of the ECT is negative and statistically significant at the 5% level in only two equations where Δx (economic growth) and Δz (carbon dioxide emissions) are dependent variables.[9] These results imply that there is a bidirectional long-run causality (feedback effect) between CO_2 emissions and economic growth, a unidirectional long-run causality running from energy consumption to economic growth, a unidirectional long-run causality running from energy price to economic growth, a unidirectional long-run causality running from energy price to CO_2 emissions and a unidirectional long-run causality running from energy consumption to CO_2 emissions. Fig. 4 schematizes the long-run causal relationships between the four series for Saudi Arabia.

The results of short run Granger causality tests presented in Table 9 indicate the existence of a short term unidirectional Granger causality that runs from CO_2 emissions to energy consumption, a unidirectional Granger causality running from energy consumption to economic growth, a unidirectional Granger causality running from CO_2 emissions to economic growth, and a unidirectional Granger causality running from energy price to CO_2 emissions. The absence of causality in the two directions between

[7] The values of AIC and SC are equal, respectively, to −4.92 and −4.06.

[8] Both AIC and SC are minimal for a lag length equal to one.

[9] The VECM cannot be reduced here to only one equation and the cointegrating vector appears in these two equations where Δx and Δz are dependent variables.

Table 6
Results of Johansen cointegration tests.

Number of cointegrations	Trace test				Max–Eigen test		
	Eigenvalue	Trace Statistic	5% critical value	1% critical value	Max–Eigen statistic	5% critical value	1% critical value
None[bd]	0.667	88.150	53.12	60.16	40.722	28.14	33.24
At most 1[bc]	0.493	47.427	34.91	41.07	25.199	22.00	26.81
At most 2[ac]	0.349	22.228	19.96	24.60	15.905	15.67	20.20
At most 3	0.157	6.322	9.24	12.97	6.322	9.24	12.97

[a]([b]) denotes rejection of the hypothesis at the 5% (1%) level using the trace test.
[c]([d]) denotes rejection of the hypothesis at the 5% (1%) level using the Max–Eigen test.

Table 7
Results of VECM normality residual test.

	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)	Joint
Jarque–Bera statistic	0.252	4.033	2.144	1.898	8.328
Probability	0.881	0.133	0.342	0.387	0.402

Table 8
Results of VECM autocorrelation and heteroskedasticity residual tests.

	Autocorrelation tests		VEC residual heteroskedasticity tests	
	LM test	Portmanteau test	No cross terms	Includes cross terms
Statistic	8.525	176.923	108.403	216.845
Probability	0.931	0.466	0.265	0.196

energy price and energy consumption is also established in the short run.

3.4. *Results of variance decomposition and impulse response function*

The results of variance decomposition approach are shown in Table 10. It is shown that a 78.936% of energy consumption is explained by its own innovative shocks whereas the contributions of economic growth, energy price and CO_2 emissions to energy consumption are equal to 18.255%, 2.321% and 0.487%, respectively. One standard deviation shock in economic growth explains 51.967% itself. Energy consumption contributes to economic growth by 7.605% and the share of CO_2 emissions to economic growth is 13.649%. One standard deviation shock stemming in energy price explains 26.778% of economic growth.

The results also show that a 63.656% of CO_2 emissions are explained by its own innovative shocks. The contributions of energy consumption, economic growth and energy price to CO_2 emissions are 12.355%, 4.918% and 19.068%, respectively. A 9.203% of energy price is explained by one standard deviation shock in energy consumption. The share of economic growth to contribute in energy price is important. It represents 51.894%. A 38.651% of energy price is contributed by its own standard shocks whereas the share of CO_2 emissions is very negligible (0.25%).

The results of impulse response function are shown in Fig. 5. The impulse response function shows the reaction in one variable due to shocks stemming in other variables. The response in energy consumption first rises then stagnates due shocks stemming in economic growth. The response in economic growth first increases then goes down and becomes negative due to shocks stemming in energy consumption whereas the response in economic growth to shocks stemming in energy price is increasing. The responses of per capita CO_2 emissions to per capita energy consumption and economic growth are decreasing in time.

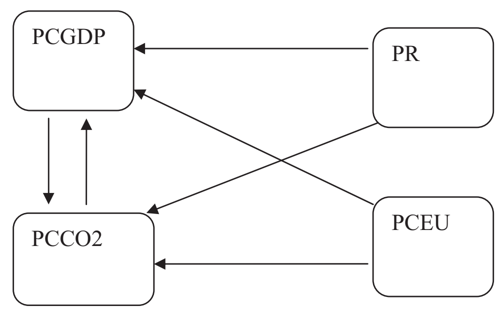

Fig. 4. Long-run causality between energy consumption, CO_2 emissions, energy price and economic growth.

4. Discussion

All the long run causal relationships found are expected and conform to the Saudi economic reality. From the results of long run causality, we deduce that controlling for CO_2 emissions has an adverse effect on economic growth in the long term in Saudi Arabia. Also, economic growth will eventually lead to CO_2 emissions. However, according to the results of response function, we expect a decreasing linear relationship between real per capita GDP and per capita CO_2 emissions. Also, the results of variance decomposition indicate that the share of economic growth in explaining CO_2 emissions is minimal comparatively to those of energy price and energy consumption. The results of variance decomposition for energy price are conforming to those given by Granger causality test where energy price causes CO_2 emissions in both the short and long run. The result of the unidirectional causality running from energy consumption to carbon dioxide emissions is expected as the overuse of energy may lead to greater CO_2 emissions.

The growth hypothesis is also verified for Saudi Arabia. Energy consumption and energy prices are the drivers of long term economic growth. According to the results of variance decomposition, it seems that energy price is the most important variable in explaining economic growth. This result is not surprising for an OPEC member such as Saudi Arabia where the rises in oil prices contribute by a big part to economic growth. The most interesting result is that while unidirectional causality running from energy consumption to economic growth is detected for Saudi Arabia, energy consumption is not an important factor in explaining innovation to economic growth.

We believe that these results are expected given that energy sector represents an important part of economic activities in Saudi Arabia. The economic growth seems to be more important than energy price and CO_2 emissions in explaining the variation in energy consumption for the 10-year horizon. What is surprising is that the contribution of CO_2 emissions in explaining energy consumption is very minimal whereas CO_2 emissions are the only variable that causes energy consumption in the short run. We also find that energy price does not Granger cause energy consumption

Table 9
Results of Granger causality tests.

Dependent variable	Short-run causality (χ^2-Wald statistics)				Long-run causality	
	Δy	Δx	Δp	Δz	ECT_{t-1}	
					Coefficients	*t*-statistics
Δy	–	0.414 (0.52)	0.157 (0.69)	2.688 (0.10)	0.061	1.441
Δx	3.010 (0.08)	–	1.696 (0.19)	4.473 (0.03)	−0.066	−2.883
Δp	0.031 (0.86)	0.561 (0.45)	–	0.541 (0.46)	0.413	2.591
Δz	0.054 (0.82)	0.052 (0.81)	4.289 (0.03)	–	−0.176	−3.091

Values in parentheses are *p*-values.

Table 10
Variance decomposition of the four variables.

Period	S.E.	LNPCEU	LNPCGDP	LNPR	LNPCCO2
Variance decomposition of LNPCEU					
1	0.097825	100.0000	0.000000	0.000000	0.000000
2	0.166131	95.13304	2.970907	1.448287	0.447764
3	0.237273	90.13971	6.615656	2.502332	0.742297
4	0.306189	86.48329	9.799808	2.903329	0.813571
5	0.370160	83.91499	12.33676	2.964753	0.783496
6	0.428046	82.12181	14.28561	2.874386	0.718203
7	0.479822	80.86742	15.75365	2.730767	0.648161
8	0.526068	79.98841	16.84675	2.579891	0.584952
9	0.567619	79.37138	17.65597	2.441021	0.531633
10	0.605345	78.93663	18.25502	2.320512	0.487846
Variance decomposition of LNPCGDP					
1	0.054048	4.841971	95.15803	0.000000	0.000000
2	0.095965	4.823539	91.41501	2.235546	1.525909
3	0.132117	3.172177	87.19830	5.910623	3.718900
4	0.162931	2.088384	81.78868	10.11835	6.004576
5	0.189660	1.981409	75.65526	14.26424	8.099098
6	0.213330	2.689069	69.51879	17.94313	9.849009
7	0.234581	3.866172	63.92093	20.98898	11.22392
8	0.253796	5.198150	59.12274	23.41059	12.26853
9	0.271256	6.478595	55.16483	25.30226	13.05432
10	0.287222	7.605031	51.96709	26.77801	13.64987
Variance decomposition of LNPR					
1	0.315694	0.055974	25.15258	74.79145	0.000000
2	0.442300	4.380355	36.12125	58.71875	0.779650
3	0.566206	7.096639	42.44461	49.71220	0.746551
4	0.681212	8.714009	46.40826	44.22991	0.647822
5	0.786745	9.484582	48.81008	41.16868	0.536662
6	0.882502	9.750383	50.25036	39.55503	0.444223
7	0.969254	9.741049	51.08649	38.79890	0.373567
8	1.048173	9.598824	51.54868	38.53169	0.320802
9	1.120521	9.405130	51.78606	38.52778	0.281034
10	1.187469	9.203669	51.89473	38.65128	0.250328
Variance decomposition of LNPCCO2					
1	0.122631	25.78225	11.35481	0.806047	62.05689
2	0.165753	25.62723	11.08127	3.428180	59.86333
3	0.194408	23.52579	10.41840	6.318633	59.73717
4	0.216413	21.20172	9.406045	9.256758	60.13548
5	0.234958	19.04260	8.335814	11.93934	60.68224
6	0.251563	17.17288	7.373193	14.18635	61.26758
7	0.266950	15.60401	6.568476	15.95996	61.86755
8	0.281466	14.30541	5.910613	17.30893	62.47504
9	0.295296	13.23599	5.369953	18.31677	63.07729
10	0.308548	12.35566	4.918678	19.06886	63.65681

in the long run even that domestic energy prices are very low in Saudi Arabia. This result is expected because fossil fuels are well subsidized in Saudi Arabia and hence the proxy of energy price does not reflect correctly the domestic energy prices practiced in the different types of economic activities or sectors.

We turn now to the analysis and discussion of short run Granger causality test results. We observe that results of short run causality tests are conform to those obtained in the long run. The main findings are that reducing CO_2 emissions and energy consumption may hamper short term economic growth in Saudi Arabia.

A forefront question in energy economics is: does energy consumption cause economic activity, or does the reverse occur? In contrast to the neo-classical theory that states energy is neutral to economic growth, we find that for Saudi Arabia, energy consumption Granger causes economic output in the short and long term. Our results differ from those of Al-Iriani, Mehrara, Damette and Seghir [8,9,16] in the long run. Al-Iriani [8] found a unidirectional causality from economic growth to energy consumption in the short and long term for six countries of the Gulf Cooperation Council including Saudi Arabia. Mehrara [9] found similar results for 11 oil exporting countries from 1970 to 2002. Damette and Seghir [16] found short term unidirectional causality from energy consumption to economic growth and long term unidirectional causality from economic growth to energy consumption for 12 oil exporting countries including Saudi Arabia. Our results are also different from those of Khalid [14]. He found the absence of causality in the short run and a unidirectional causality running from economic growth to energy consumption in long run. Our results confirm those obtained by Alkhathlan and Javid [17]. It is unique for two reasons. Firstly, we focus solely on Saudi Arabia, thus omitting heterogeneity between different countries that differ politically and economically. Secondly, we include energy price in our analysis, which is an important variable for an oil country.

5. Conclusion and policy implications

In this study, we analyze the dynamic causal relationships between energy consumption, energy price and economic growth in Saudi Arabia using the Johansen multivariate cointegration approach and incorporate CO_2 emissions as a control variable. The inclusion of energy price as an additional variable in the model comparatively to previous studies on Saudi Arabia is of particular interest. Notwithstanding it provides evidence on the dynamic interaction of the system variables. The results indicate that there exists at least a long run equilibrium relationship between energy consumption, energy price, carbon dioxide emissions, and economic growth. We obtain a unidirectional causality from energy consumption to economic growth in the short and long run for Saudi Arabia. Moreover, energy consumption, energy price and economic growth cause CO_2 emissions in long term. Overall, the energy-led growth hypothesis is valid for Saudi Arabia. However, the result of the variance decomposition analysis shows that the share of energy consumption in explaining economic growth is minimal in Saudi Arabia.

The results imply that a policy aiming at reducing energy consumption and controlling for CO_2 emissions could slow economic growth but not significantly. Thus, any energy conservation

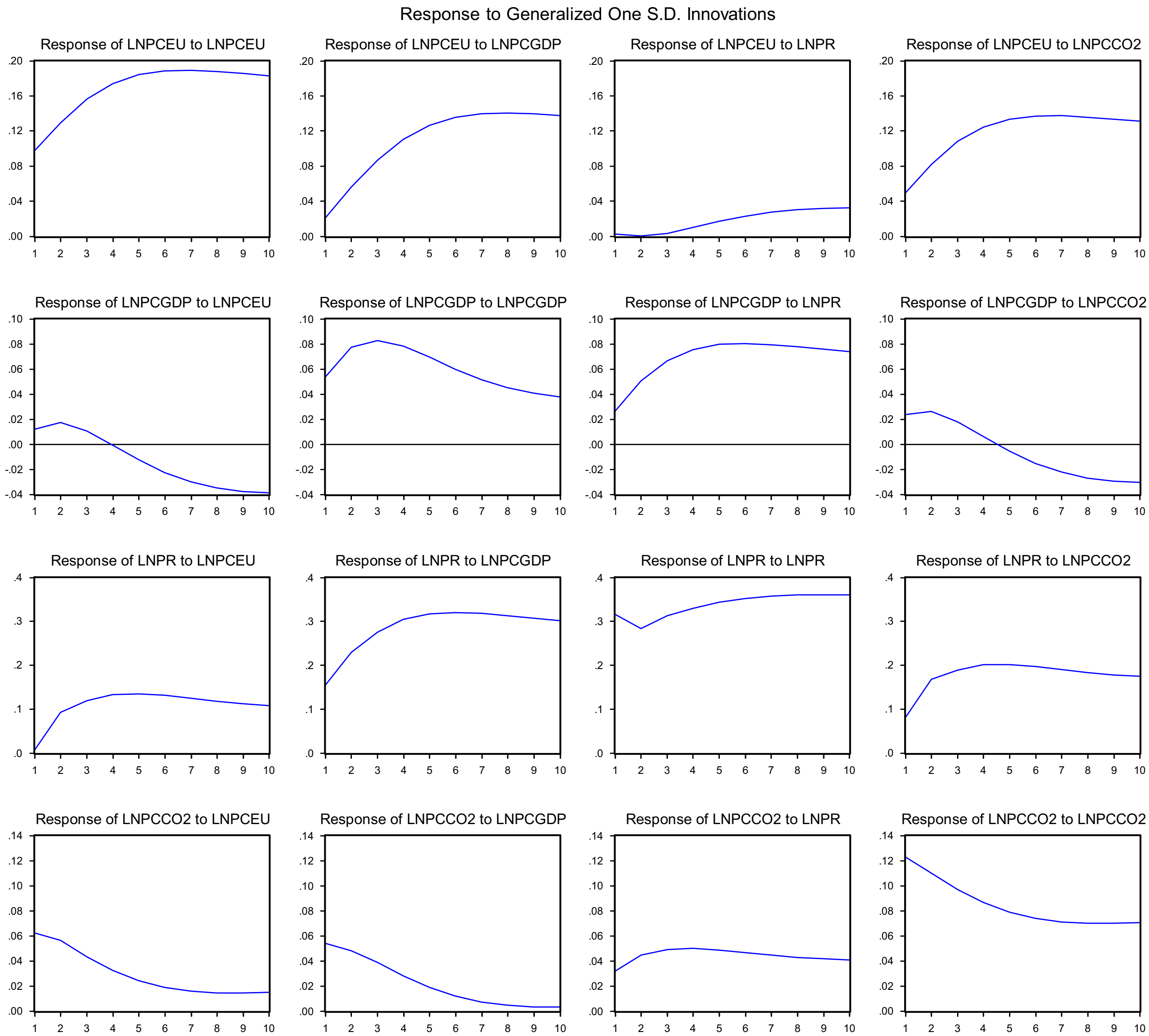

Fig. 5. Responses of variables to one S.D. innovations.

measures undertaken should pay considerable attention to the adverse effects on economic growth. Saudi Arabia has to find ways of providing energy services while simultaneously addressing the environmental impacts associated with the different uses of energy. Saudi Arabia is among the least energy-efficient economies. According to WDI [1], Saudi Arabia produced less than US$ 3.70 of economic output for every kilogram of oil equivalent in 2010, compared to the global average of US$ 6.20. This shows the intensity of energy economic activities in Saudi Arabia which is explained by overuse of energy and local low prices for fossil fuel consumption. Saudi Arabia has a high level of energy use per capita. Its energy use per capita was close to 6168 kg of oil equivalent in 2010, compared to the global average of 1851 kg of oil equivalent. Moreover, its energy consumption relies solely on fossil fuels (oil and natural gas). This makes Saudi Arabia as one of the largest global polluters in the world. Carbon dioxide emissions per capita were close to 16 metric tons in 2009, compared to the global average of 4.7 metric tons.

The overuse of energy due to its low price will lead to serious problems in the future, since it is provided in ways that are non-renewable, or subject to depletion. This overuse not only aggravates local pollution, traffic congestion, and global warming, but also reduces the resources for future generations. This is why it will cause a dilemma for the coming generations.

Hence, to ensure sustainable economic growth, Saudi Arabia should invest in clean energies (renewable energy resources: solar and wind) and adopt measures of energy efficiency [33]. Since global warming is becoming more serious, investment in renewable energies and more efficient energy use are needed to minimize the CO_2 emissions. At the same time, the different sectors must be encouraged to adopt advanced technology that minimizes pollution.

Saudi Arabia has resources to acquire more advanced technology that enables it to do more to reduce its energy use and hence its pollution. In Saudi Arabia, there is a vast potential for renewable energy sources, as wind power is estimated at 11 GW generation capacities. Investing in the use of renewable energy sources like solar and wind power should be an urgent necessity to control for CO_2 emissions. Our results concord with policy recommendations of Cinti [34] who stated that Saudi Arabia should invest in renewable energy resources to reduce the fossil

fuel consumption and CO_2 emissions to meet climate change policies. Renewable energy resources serve internal market and new economic cities to avoid overexploitation of fossil fuels, leading to reduction of the CO_2 emissions. This policy can also save the quantity of fossil fuels (oil and natural gas) available for export, the main source of the Saudi's welfare and development [34]. Furthermore, energy saving technologies and increased energy efficiency may increase the economic growth.

There is room for future research concerning Saudi Arabia under this theme. For example, analysis at the disaggregated level is nonexistent for Saudi Arabia. Different sectors of economic activity have varying intensities of energy, and over time, sector importance can change. Investigating the relationship between energy consumption, CO_2 emissions, and economic output at a disaggregated level (e.g. transport sector) would add value to this analysis. Studying the relationship between energy consumption and economic growth using a production function approach to include labor, capital stock, human capital and exports as variables of control, is an interesting direction for future research.

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